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Presence of Pharmaceuticals and Personal Care Products (PPCPs) in Soil Irrigated with Municipal Wastewater

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By

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Division of Environmental Science

with Honors

May 2016

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Abstract

Pharmaceuticals and personal care products (PPCPs) are largely produced, consumed, and detected readily in wastewater effluent. Municipal wastewater land application to managed forests is an important treatment and disposal practice globally, with 86 municipal facilities located in North Carolina. However, the concentrations and transport of PPCPs and their potential impacts in these systems are largely unknown. The objective of this study was to assess PPCPs in forested soils at a municipal land application site in North Carolina, U.S.A. Soil cores were hand-augured at the surface (0-10 cm) and at depth (50-60 cm) along two transects within the wastewater irrigation area and at a reference site outside of the irrigation area. Thirty-three PPCP analytes were targeted using solid-phase extraction (SPE) and concentration, and separated and quantified via liquid chromatography - mass spectrometry (LC-MS/MS). Relationships between PPCP analyte concentrations and soil characteristics (e.g. soil depth, soil texture, carbon concentration, humic matter content, cation exchange capacity, and pH), were evaluated. From this study, 25 of the 33 targeted PPCP analytes were detected in the soil at very low concentrations (ng/g of soil), indicating leaching and potentially some mitigation by the forest system. Generally, PPCPs were present at higher concentrations in the surface soil. No significant correlations were observed between soil characteristics and the presence and concentration of PPCPs; however, cation exchange capacity and carbon content did positively correlate with the concentration of carbamazepine, a rather persistent chemical detected at every site in only the surface horizon.

Keywords: PPCPs, municipal wastewater land application, soil, carbon, cation exchange capacity, carbamazepine.

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I would like to acknowledge the UNC-Chapel Hill Biomarker Mass Spectrometry Facility for instrument use with support from the National Institute of Environmental Health Sciences (NIEHS), the Superfund Basic Research Program (P42ES5948), and the UNC Center for Environmental Health and Susceptibility (P30ES010126).

Introduction

Pharmaceuticals and personal care products (PPCPs), a wide range of chemical compounds (Table 1), are ubiquitous in waterways throughout the U.S. and other parts of the world (Peng et al., 2008; Gros et al., 2010). Koplin et al. (2002) reported that PPCPs were detected in 95 of 139 streams within thirty U.S. states and others have reported PPCPs in surface waters dominated both by agricultural and anthropogenic land uses (Christian et al., 2003; Benotti et al., 2009). Although the concentrations of these micro-pollutants in water are generally low (μg/L) and many are not persistent chemicals, their presence, continual introduction, and potential increase in concentration over time is of increasing concern (Daughton & Ternes, 1999; Drillia et al., 2005; Suárez et al., 2008). The development of bacterial resistance (Chee-Sanford et al., 2009), endocrine disrupting effects (Olmstead et al., 2000; Falconer et al., 2006), and ecotoxicity in both aquatic and terrestrial environments (Daughton & Ternes, 1999; Carlsson et al., 2006; Santos et al., 2010) has been well documented, but the long term impacts of PPCPs on the environment and human health are still relatively unknown.

Modern, conventional wastewater treatment plants are designed for the removal of nutrients, bacteria, and pathogens; however, the removal of PPCPs is found to be variable and incomplete (Daughton & Ternes, 1999; Suárez et al., 2008, Karnjanapiboonwong et al., 2011). Treatment methods to remove PPCPs from wastewater are often costly and are currently not implemented. The land application of wastewater is a common treatment practice globally (Karnjanapiboonwong et al., 2011; Chen et al., 2013), with 86 municipal facilities in the state of North Carolina, of which 50 percent land-apply to forests (Nielsen 2011). The forest-soil and plant system acts as a

natural filter for nutrients and regulated contaminants. When compared to a conventional treatment plant of similar treatment volume, land application is more cost effective and can provide additional ecosystem services, particularly if wastewater is irrigated on forest lands. In these systems, PPCPs can be transported both vertically and horizontally through the soil matrix, eventually reaching groundwater and surface waters (Karnjanapiboonwong et al., 2011, McEachran et al., 2016). Removal efficiencies of 90% to 95% have been quantified for regulated organic chemicals (USEPA 2006, Crites, 2014).

Table 1: Chemicals classified as PPCPs.

Pharmaceuticals and personal care products
Antibiotics
Antimicrobials
Non-steroidal anti-inflammatory drugs (NSAIDs)
Prescription drugs
Over-the-counter drugs
Caffeine
Bisphenol-A
Pesticides
Cosmetics

(Daughton & Ternes, 1999)

Soils have the ability to adsorb PPCP analytes to restrict their mobility (Casey, et al., 2003; Kinney et al., 2006; Chefetz et al., 2008; Karnjanapiboonwong et al., 2010; Chen et al., 2013). The characteristics of a soil, such as organic matter content, clay content, cation exchange capacity, pH, and additionally the properties of specific PPCP analytes, such as water solubility and the octanol-water partition coefficient, have an

effect on the adsorption-desorption potential and ultimate fate of these contaminants (Drillia et al., 2005). Soil type and mineral particle size have been determined to play a crucial role in the sorption potential of PPCPs, with coarser textured soils having a smaller sorption potential than finer textured soils due to the greater surface area of smaller particles, such as clay (Casey et al., 2003; Drillia et al., 2005; Jones et al., 2005; Gibson et al., 2010). High organic matter content can inhibit the mobility of PPCPs (Casey et al., 2003; Drillia et al. 2005; Gibson et al. 2010), while lower organic matter content can increase PPCP mobility and the potential for the contamination of groundwater and surface water sources (Fan et al. 2006). Soil depth has also been found to be a contributing factor in the sorption of PPCPs. Chen et al. (2013) found that nine common PPCPs were not present in the soil profile beyond 90 cm, which suggests that most PPCPs are detectable in the upper surface soil horizons rather than at deeper soil depths.

The role of soils in the transport and fate of land-applied PPCPs in forested land-application systems remains undefined. PPCPs have been previously reported in groundwater and surface waters at the municipal wastewater land application site used in this study at concentrations much lower than quantified in the wastewater effluent, indicating some potential mitigation by the forest-soil system (McEachran et al., 2016).

The objective of this study was to evaluate the presence of PPCPs in forest soils at two depths, 0-10 cm and 50-60 cm, at a municipal wastewater land application site in North Carolina, U.S.A. The impact of soil characteristics on the sorption potential of thirty-three targeted PPCPs was examined to determine the suitability of the forest-soil system at this site for mitigation of PPCP contamination. The findings of this research

will fill improve our understanding of the presence and transport of PPCPs in soil, and indicate the soil characteristics that influence adsorption. This can inform wastewater land application system design for effective PPCP mitigation.

The United States Environmental Protection Agency (EPA) has established a list of 126 Priority Pollutants for regulation; however, the current 2014 list does not include pharmaceuticals (USEPA, 2014). In January 2015, the EPA released 100 chemicals for the Drinking Water Contaminant Candidate List 4 (CCL4). This publication, re-evaluated every five years, identifies contaminants that are known or anticipated to occur in public water systems, however imposes no regulation requirements. The current CCL4 list includes five of the thirty-three analytes targeted in our study, including: erythromycin, 17β-estradiol, estriol (E3), 17α-ethynylestradiol (EE2), and estrone (E1) (USEPA, 2015).

Methods

Study area and Sampling

A municipal wastewater land application site in Jacksonville, North Carolina, U.S.A. supports the secondary treatment of municipal wastewater for the town's 70,000 residents. The facility receives approximately to 19,000 m^3 of wastewater per day ("Welcome to an Engaged Community," 2015). The secondary treatment includes four steps: storage and biological treatment in lagoons, disinfection, screening and grit removal, and spray irrigation of treated wastewater in forested areas ("Welcome to an Engaged Community," 2015). The treated municipal wastewater is irrigated through 18,000 sprinkler nozzles onto over 930 hectares of 35-year mixed pine/hardwood forested land. Annually the site is irrigated with approximately 3,212 mm of wastewater per

hectare and receives an annual rainfall of approximately the same amount. The soils within the test area are Ultisols of the Norfolk series (Birch, 2015), characterized as a very deep, well-drained, loamy fine sand originating from marine or fluviomarine deposits (NRCS, 2005) (Table 2). The irrigation system is setup to prevent overland flow of wastewater, thus resulting in all irrigated wastewater to be held in the soil, evapotranspirated, or recharged to groundwater (Birch, 2015).

Sites were selected for soil collection along two transects previously identified for the investigation of wastewater movement to groundwater and surface water: TA 1, TA 2, TB 1, TB 2 (Figure 1) (Birch, 2015; McEachran et al., 2016). These transects include upland areas within wastewater irrigation areas (TA 1 and TB 1) moving down gradient towards TA 2 and TB 2 ultimately towards small tributaries. A reference well was sampled in a nearby non-irrigated area. Sampling occurred in June and July of 2015 for a total of three sampling events (n=3). Sample collection followed the protocols previously outlined in the literature with minor changes (Sparks et al., 1996; Chefetz et al., 2008). Two composite soil samples were collected at each location: one at the surface (0-10 cm) and one deep (50-60 cm). A hand auger was used to collect three surface and three deep samples at each site. Each composite sample was mixed and quartered in a stainless steel bowl and placed in a pre-cleaned, baked, labeled mason jar. All sampling materials were rinsed with deionized water and acetone between samplings. All samples were refrigerated at 4 degrees Celsius until laboratory analysis was performed.

Table 2: Soil characteristics at each sampling location and depth.

	TA 1		TA 2		TB 1		TB 2		Reference	
	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm
Soil Classification	Loamy fine sand	Sandy loam	Loamy fine sand	Loamy fine sand	Fine sand	Sandy loam	Loamy fine sand	Fine sand	Loamy fine sand	Sandy loam
% Field Moisture	24	20	36	20	9.0	11	6.5	7.6	18	11
% Sand	83	75	83	81	87	76	82	91	80	76
% Silt	12	12	13	13	11	10	13	8.2	13	13
% Clay	5.2	12	4.7	5.5	1.8	14	5.6	1.3	7.1	10
pH	6.5	7.3	7.2	6.9	6.9	6.4	7.4	7.3	4.8	4.8
Buffer pH	7.8	8.0	7.9	8.0	8.0	7.9	8.0	7.9	7.3	7.6
CEC (cmolc/kg)	6.0	2.3	7.4	1.2	6.0	2.1	9.9	3.1	4.4	2.0
% Carbon	1.7	0.35	1.9	0.28	1.7	0.31	2.0	0.70	2.3	0.21
% Nitrogen	0.07	0.03	0.05	<0.02	0.06	0.02	0.06	<0.02	0.08	<0.02
% Humic Matter	0.33	0.18	0.62	0.29	0.24	0.23	0.47	0.52	1.7	0.52
P (g/m2)	4.5	2.9	11	1.2	4.6	1.1	5.5	5.5	14.7	0.67
K (g/m2)	8.4	26	16	15	6.9	24	17	21	11.3	1.9
Mg (g/m2)	21	13	34	5.7	29	13	29	15	9.3	3.3
Ca (g/m2)	193	60	239	27	207	45	380	85	50	12
Mn (g/m2)	0.78	0.22	0.78	0.11	1.7	0.67	4.9	1.0	0.78	0.11

	TA 1		TA 2		TB 1		TB 2		Reference	
	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm
S (g/m2)	2.5	1.3	1.6	1.5	1.0	11	2.7	0.90	4.1	8.4
B (g/m2)	0.11	0.15	0.22	0.06	0.19	0.29	0.49	0.11	0.04	0.02
Zn (g/m2)	0.13	0.18	0.11	0.17	0.22	0.08	0.21	0.11	0.83	0.13
Fe (g/m2)	33	18	49	26	22	17	26	27	79	19
Cu (g/m2)	0.06	0.07	0.07	0.08	0.07	0.06	0.07	0.06	0.47	0.06
% K	1.6	13	2.5	15	1.3	12.9	2.0	7.8	3.0	1.1
% Mg	13	21	17	18	18	22	11	18	7.9	6.0
% Ca	72	57	72	50	77	47	85	61	25	14

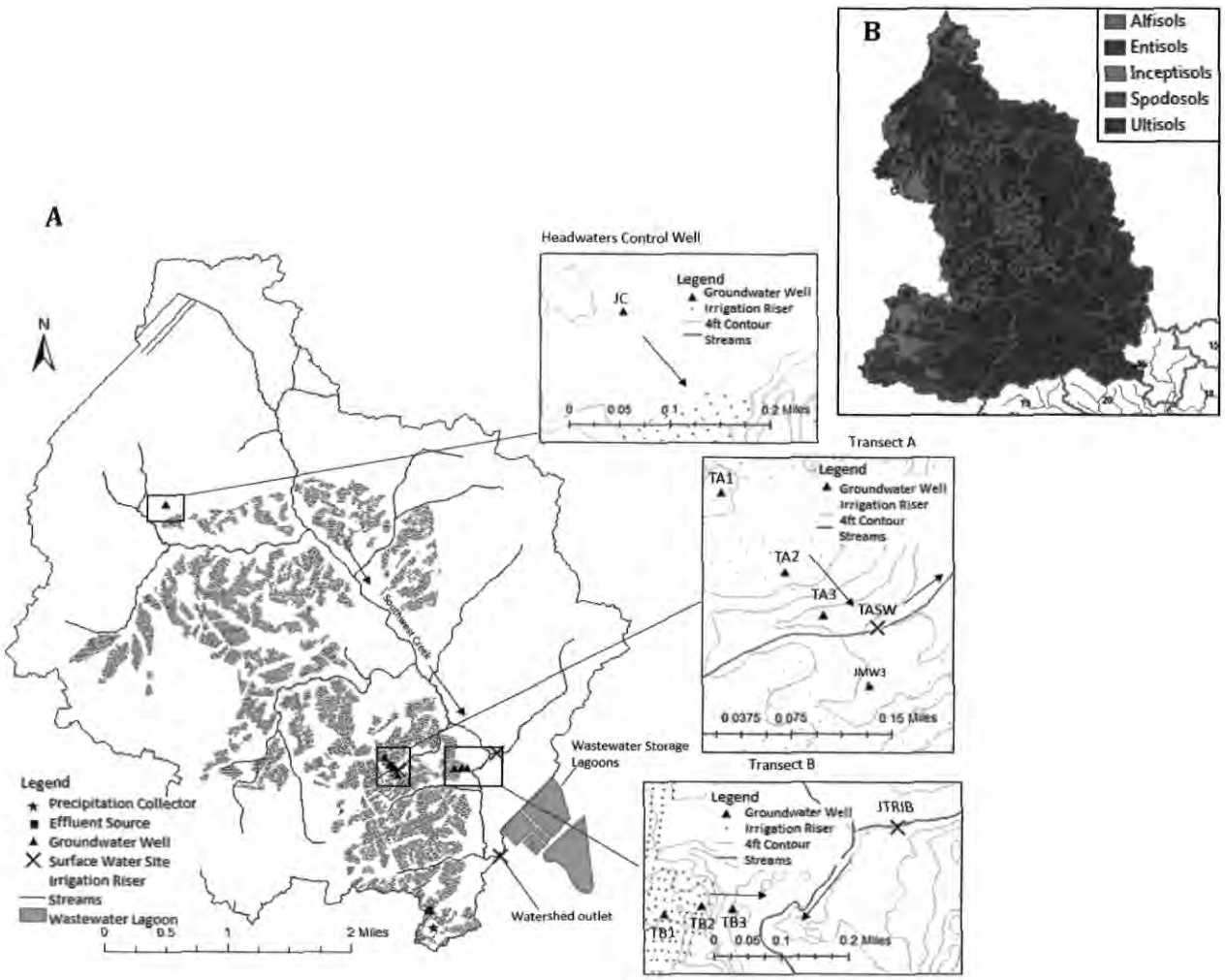

Figure 1: Municipal wastewater land application site in Jacksonville, North Carolina. Transect A, Transect B, and the Reference sites are shown (A) with the corresponding soil orders (B). (Birch, 2015)

Water and Solvent Extraction

Extraction of PPCPs from soils followed the U.S. EPA Method 1694 with minor adjustments (USEPA, 2007). Samples were first extracted using only deionized water to determine the readily soluble fraction of PPCPs. Approximately 10 g of soil was placed in labeled Oak Ridge Teflon tubes, 15 mL of deionized water was added, and the tubes were shaken to create a slurry. For all samples, 50 µL of 1 ppm surrogate internal

standard mix and an additional 10 mL of deionized water were added to the slurry. Samples were shaken on a platform shaker at 45 RPM for two hours, centrifuged for twelve minutes at 1,000 RPM, and the water fraction was decanted into pre-cleaned and baked amber bottles. The process was repeated with an additional 25 mL of deionized water. Finally, 100 mL of deionized water was added to each water fraction sample to dilute for ease of solid phase extraction (SPE) clean up and pre-concentration.

The remaining soil from the water extraction was used for the solvent extraction and 25 mL of acetonitrile was added to each tube. The samples were shaken on a Platform Shaker at approximately 45 RPM for one hour, centrifuged for twelve minutes at 1,000 RPM, and the solvent fraction was decanted into amber bottles. The process was repeated with 15 mL of acetonitrile and 10 mL of methanol to maximize PPCP extraction. Solvent extracts were evaporated to 20-30 mL under a nitrogen stream and then 150-200 mL of deionized water was added for SPE.

Solid Phase Extraction and Analysis

Clean up procedures were completed following the method in McEachran et al. (2016) using Oasis HLB SPE cartridges. The cartridges were pre-conditioned using 6 mL of methanol and 6 mL of deionized water and the sample was loaded through the cartridges under light vacuum. Once the sample was fully loaded onto the SPE cartridges, the cartridges were dried for 15 minutes, washed with 2 mL of deionized water to remove impurities, and dried again for an additional 15 minutes. Cartridges were eluted with 8 mL of methanol followed by 4 mL of 0.1% TFA in methanol.

Eluents were then evaporated, combined, and reconstituted with 200 µL of 50% methanol and 50 µL of reference standard in LC-MS vials. LC-MS vials were stored at -80 C until separation, detection, and quantification via LC-MS/MS.

Thirty-three analytes were targeted from a suite of antibiotics, antimicrobials, hormones, NSAIDs, prescription and over-the-counter drugs, cotinine, caffeine, DEET, and bisphenol A. The compounds of interest in this study were selected based upon their presence in the groundwater and surface water at the site from a previous study (McEachran et al., 2016). Separation, detection, and quantification of targeted analytes has been previously described (McEachran et al., 2016). Briefly, two separation and analysis methods were used. In the first method target compounds were separated using an Acquity UPLC BEH (Ethylene Bridged Hybrid) Shield RP18 column from Waters. Compounds were identified and quantified on a Thermo Scientific TSQ Quantum Ultra triple-quadruple mass spectrometer operated in positive electrospray ionization (ESI) mode. The second method used an Acquity UPLC BEH C18 column from Waters and the mass spectrometer was operated in negative ESI mode. Liquid chromatography and mass spectrometer operating conditions can be found in McEachran et al. (2016).

Soil Analysis

Percent of sand, silt, and clay was determined through soil particle size analysis by the hydrometer method (Sparks el al., 1996). Soil samples were analyzed for percent total carbon and nitrogen using a Perkin Elmer 2400 CHNS Analyzer (Sparks et al., 1996) at NC State Analytical Spectroscopy Service Laboratory. Phosphorous, potassium, magnesium, calcium, manganese, sulfur, boron, zinc, iron, copper, cation exchange

capacity (CEC), and pH were determined per Mehlich III and percent humic matter was analyzed via a photometric method using NaOH extraction (Mehlich, 1984) at Waters Agricultural Laboratories, Inc., Wallace, NC. The content of extractable cations was determined from the concentration using the bulk density for each soil sample.

Quality Control

Field duplicates were collected at each sampling event and analyzed as described above. Stable isotopically labeled compounds, [^{13}C] Carbamazepine and [^{13}C] 17β-Estradiol, were introduced in the soil mixture, water extracts and solvent extracts in order to determine the percent recoveries and extraction efficiencies. Additionally, blanks were used as part of the analytical method to test for instrument contamination and were run in the LC-MS the same as the samples.

Results & Discussion

Soil Physiochemical Properties

The soils present at this site are Ultisols and classified as Norfolk loamy fine sands (Birch, 2015). Particle size distribution, cation exchange capacity, pH, percent carbon, and percent humic matter were analyzed for each soil sample along the two transects and at the reference site (Figure 2). Each soil composite contained more than 75 percent sand, classifying these soils as loamy fine sands, sandy loams, or fine sands. The surface soils at TA 1, TA 2, and TB1 were composed of at least 83 percent sand, indicating rapid infiltration potential. Additionally, TA 1, TA 2, TB 1, and the reference site displayed increasing clay with depth (ranging from 5.5 to 14 percent). Soil pH was

similar throughout the profile and ranged from 6.4 to 7.4 along transect A and B. The reference site, however, was more acidic with a pH of 4.8 at both the surface and deep. More humic matter was present at the surface compared to at depth and was highest at the surface of the reference sampling location.

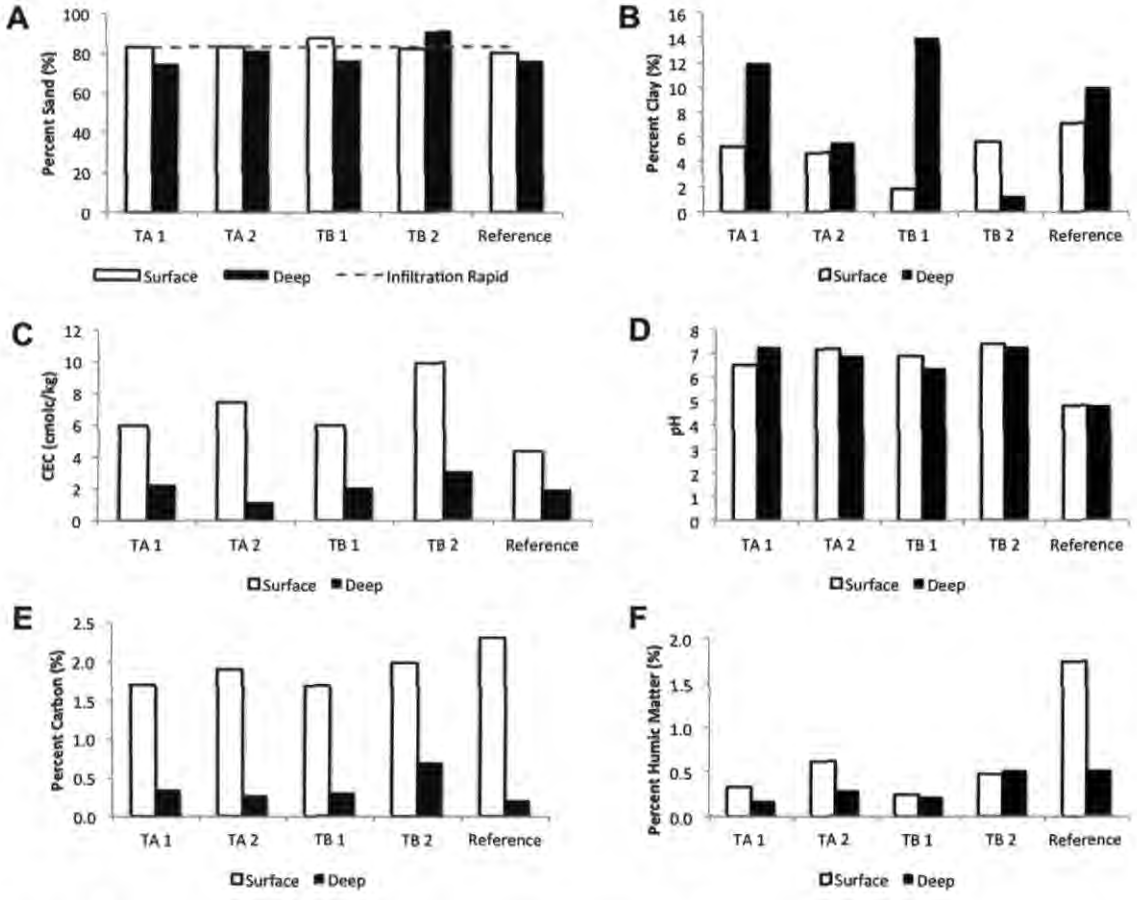

Figure 2: Physiochemical properties of soil samples: A) sand, B) clay, C) cation exchange capacity (CEC), D) pH, E) carbon, and F) humic matter.

The cation exchange capacity and percent carbon were greater in all surface soils. CEC ranged from 4.4 to 9.9 $cmol_c/kg$ at the surface and 1.2 to 3.1 $cmol_c/kg$ in the deep soil. Adsorption of compounds to organic matter is thought to be the primary physiochemical mechanism for removal of trace organics (USEPA, 2006). Soil organic matter increases water holding capacity and soil structure, and the higher specific surface

area of organic matter contributes to a higher CEC, allowing for a greater potential for cation adsorption (USEPA, 2006). Wastewater application adds organic carbon to the soil, which explains the higher organic matter content present in the surface soil. This increase in organic matter creates an environment with a higher CEC and adsorption potential (USEPA, 2006). Generally, sandy soils have a lower CEC than soils with higher clay and organic matter content (Casey et al., 2003). Therefore, the high sand content at this site has a limited ability to adsorb cations, resulting in a higher potential for leaching of irrigated wastewater. Coarse-textured soils are able to accept large quantities of water, but the applied water is not retained in the root zone for very long. Generally, medium textured-soils are best for wastewater-irrigation systems (USEPA, 2006).

PPCP Compounds

Twenty-five of the 33 PPCPs targeted in analysis were detected across all samples. The targeted compound DEET was present consistently above detection limits in the reference soil. This has been previously reported in similar analytical methods such as McEachran et al (2016); therefore, DEET was removed from further analysis. All PPCP compounds detected in the wastewater-irrigated soils have previously been detected in groundwater (McEachran et al., 2016), except atenolol, meprobamate, EE2, and triclocarban (Table 3). Ten compounds were detected consistently at all four sampling locations. Four compounds were only detected in transect A (atenonol, cotinine, salicylic acid, and trimethoprim) and estriol was only detected in transect B.

Table 3: Detected PPCP compounds listed by increasing log Kow.

PPCP Compound	log Kow	TA 1	TA 2	TB 1	TB 2
*Caffeine	-0.07	X	X	X	X
*Paraxanthine	-0.07	X			
*Cotinine	0.07	X	X		
Sulfamethazine	0.14				
Atenolol	0.16	X	X		
Lincomycin	0.20				
*Acetaminophen	0.46				
Meprobamate	0.70	X	X	X	X
*Sulfamethoxazole	0.89				
*Trimethoprim	0.91	X	X		
*Triamterene	0.98	X	X	X	X
Tylosin	1.63				
*Salicylic Acid	2.26	X	X		
*Carbamazepine	2.45	X	X	X	X
*Estriol	2.45			X	X
*Diltiazem	2.70	X		X	
Erythromycin	3.06				
*E1	3.13				X
*Naproxen	3.18	X	X	X	X
*Diphenhydramine	3.27	X	X	X	
*BPA	3.32	X	X	X	
Testosterone	3.32				
EE2	3.67	X	X	X	X
*Progesterone	3.87	X	X	X	X
*Ibuprofen	3.97			X	
*Valsartan	4.00	X			
*17β-estradiol	4.01	X	X	X	X
*Paroxetine	4.01	X		X	
Azithromycin	4.02				
*Fluoxetine	4.05	X	X	X	X
*Triclosan	4.76	X	X		X
*Gemfibrozil	4.77	X	X	X	X
Triclocarban	4.90	X			
Cholesterol	8.74				

*Present in groundwater

An average of 15 PPCP compounds were detected at each sampling location and depth along transect A and transect B (Figure 3A). A greater number of compounds were detected in the surface soil than in the deep soil, with the exception of TB 2. Fewer PPCP

compounds were detected at the reference site, outside of the irrigation area. The total concentration of PPCPs detected in the wastewater-irrigated soil was approximately 8.45 to 13.07 ng/g of soil, which is higher than in groundwater (Figure 3B). The reduction in PPCP concentration from the initial wastewater effluent could be due to leaching, biodegradation, photodegradation, volatilization (Thiele-Bruhn, 2003; Drillia et al., 2005; Loffredo & Senesi, 2006; Chefetz et al., 2008; Chen et al., 2013), and plant uptake (Loffredo & Senesi, 2006; Chen et al., 2013). The predominant compounds and classes across all samples were bisphenol A, prescription/over-the-counter drugs, and hormones (Figure 4).

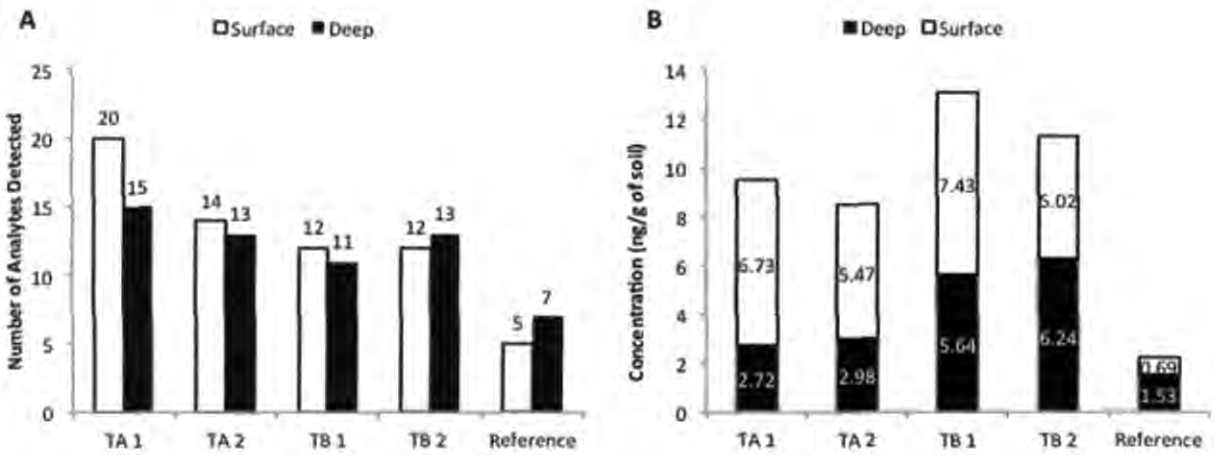

Figure 3: (A) number of PPCPs detected, and (B) concentration of PPCP compounds detected.

Higher summed total PPCP concentrations were detected at the soil surface at TA 1 (71 percent of total), TA 2 (65 percent of total), and TB 1 (57 percent of total) (Figure 6). Conversely, TB 2 showed a higher total concentration of PPCPs in the deep soil with only 45 percent of the summed total present at the surface. Summed total PPCP concentrations were dominated by BPA, EE2, meprobamate, and others (Figure 5).

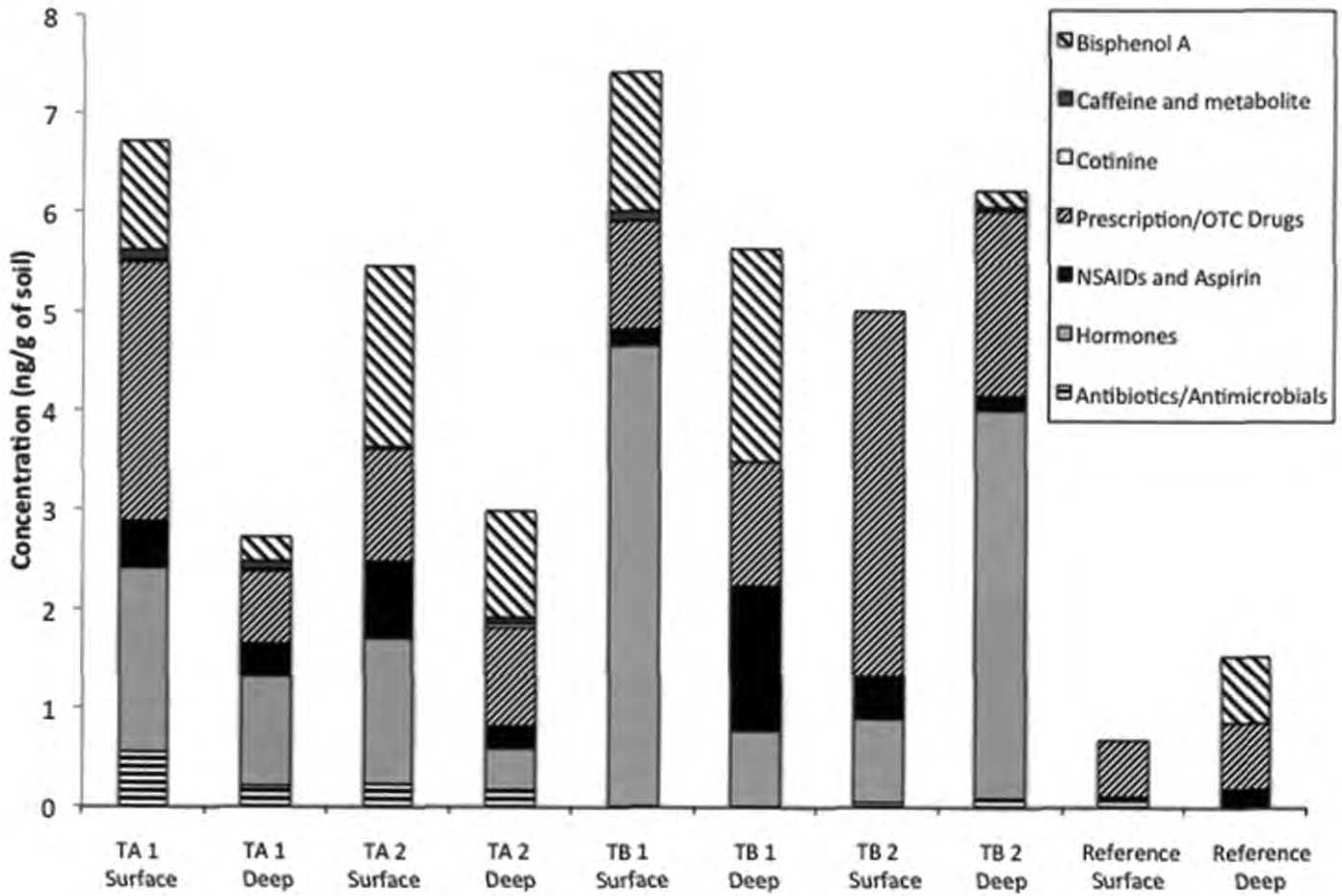

Figure 4: Concentration of PPCPs by analysis groups: Bisphenol A, caffeine and metabolite, cotinine, prescription and over-the-counter drugs, NSAIDs and aspirin, hormones, and antibiotics/antimicrobials.

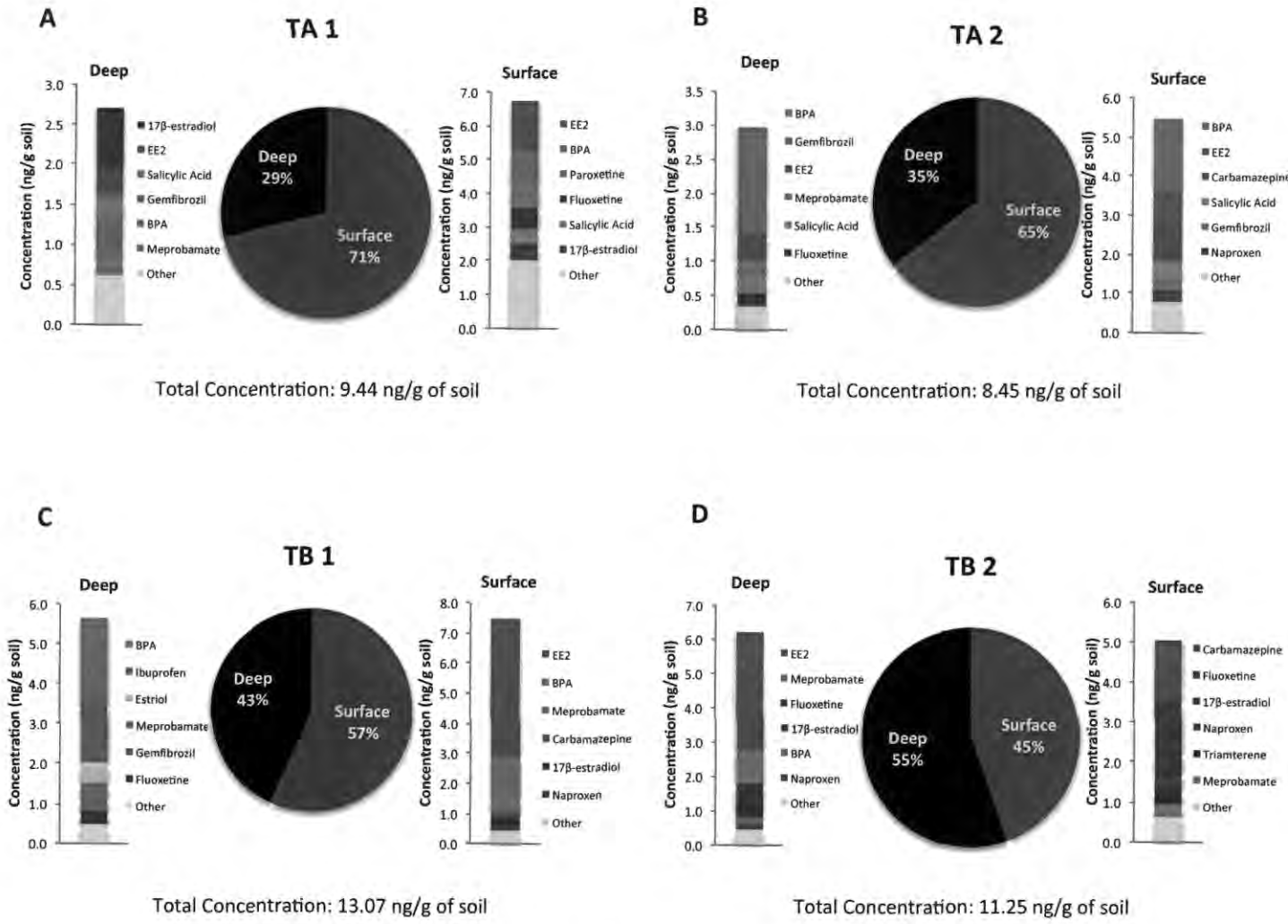

Figure 5: Profile of detected PPCPs at (A) TA 1, (B) TA 2, (C) TB 1, and (D) TB 2.

The potential of leaching into groundwater increases with PPCPs that are found to be highly mobile. Less mobile compounds have the potential to adsorb and accumulate higher in the soil profile (Chefetz et al., 2008). The mobility of these compounds is affected by their solubility, hydrophobicity, octanol-water partition coefficient (log K_{ow}), and possible competition for binding sites (Kwon & Armburst, 2008). Chemical compounds with lower log K_{ow} values are more easily extracted. Caffeine, cotinine, atenolol, trimethoprim, and others were predominately water extracted (Figure 6). Higher log K_{ow} values indicate that compounds are hydrophobic and will adhere to particles, thus requiring solvent extraction. Many of the compounds with log K_{ow} values greater than about 2.20 were primarily solvent extracted, including carbamazepine, estriol, naproxen, progesterone, and others (Figure 6). PPCPs with lower log K_{ow} values are more mobile in the soil profile and will have a high potential for leaching into groundwater sources. Karnjanapiboonwong et al. (2011) detected no caffeine in soil samples at a land application site due to the low log K_{ow} (-0.07) and high water solubility of caffeine. PPCPs with higher log K_{ow} values are less mobile in the soil profile and will have a higher potential for accumulation in the soil. Karnjanapiboonwong et al. (2011) detected no ibuprofen in groundwater, but at high concentrations in the soil. This was due to the high log K_{ow} (3.97) of ibuprofen, which results in an affinity to adsorb to soil solids. However, this is not always the case. Despite low solubility and high affinity for organic matter, estrogenic endocrine disrupting compounds appear to be almost ubiquitous in the environment (Campbell et al., 2006). Acetaminophen, having a high water solubility and low log K_{ow} value, accumulates in soil as much as other compounds with low water solubility and relatively high log K_{ow} values (Kinney et al., 2006).

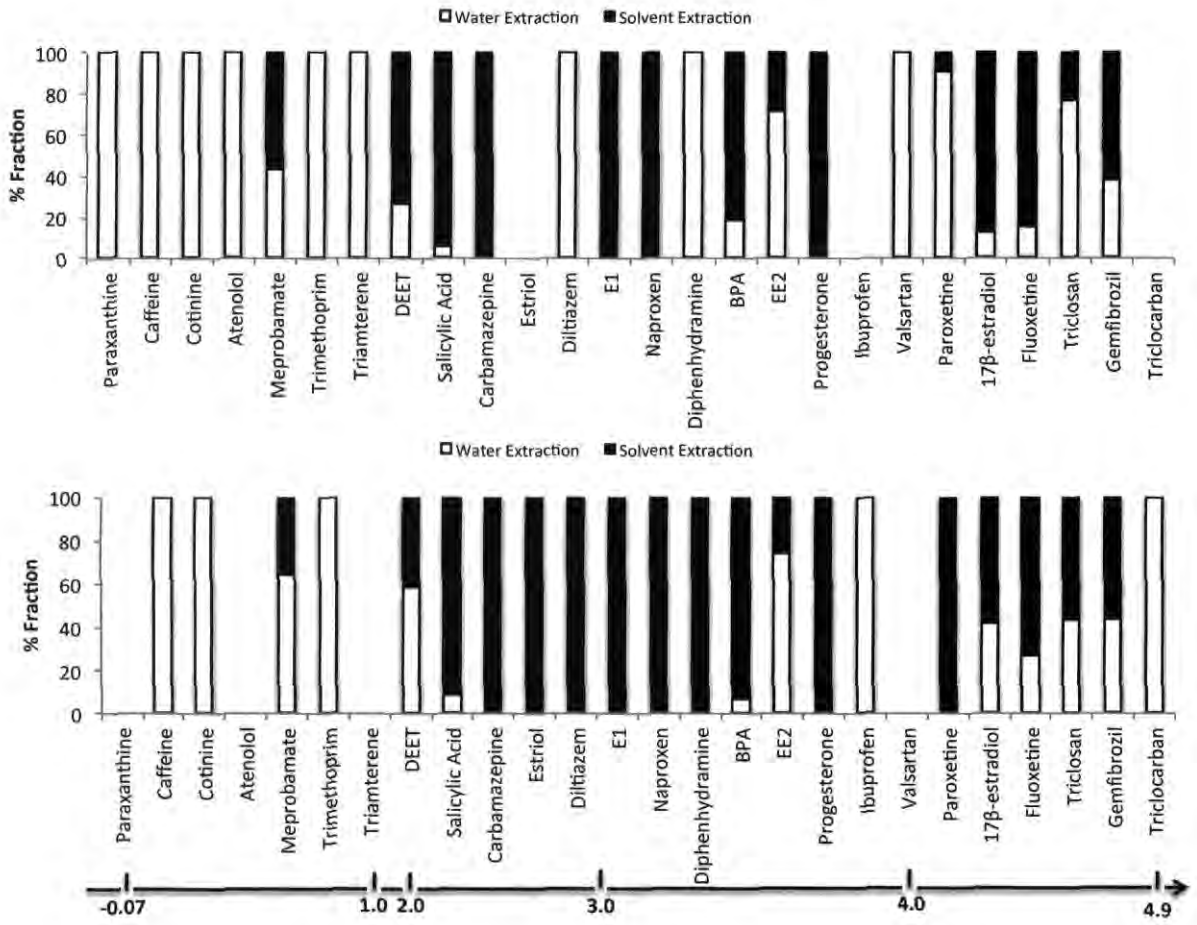

Figure 6: Percent fractions (%) of the water and solvent extractions for the (A) surface (0-10 cm), and (B) deep (50-60 cm) soil.

Soil Properties and Presence of PPCPs

The total number of compounds and summed total concentration of PPCPs in each soil sample were plotted against soil characteristics. There were no strong relationships determined, indicating that the total number of PPCPs and the total concentration of PPCP compounds were not dependent on any of the observed soil characteristics. However, Casey et al. (2003) performed a series of batch sorption experiments and determined a high sorption affinity to mineral particle size and organic

matter, associated with surface area and/or cation exchange capacity. Walker et al. (2012) measured carbamazepine at a wastewater irrigation facility and determined that the sorption of carbamazepine is strongly dependent on soil organic matter but not pH. Therefore, the affinity for PPCP compounds to adsorb to soil could be compound-specific. Additionally, the degradation rate and persistence of these micro-pollutants could impact their presence and ultimate effects in the environment over time.

Carbamazepine is a prescription drug that is used to treat seizures, nerve pain, and bipolar disorder. Carbamazepine has been classified as a slow-mobile analyte (Oppel et al., 2004; Chefetz et al., 2008). Several previous studies have found the presence of carbamazepine in the soil to be positively correlated with the amount of organic carbon, which contributes to a decreased mobility in the soil (Kinney et al., 2006; Chefetz et al., 2008; Walker et al., 2012). Carbamazepine was detected consistently at all sites along the two transects (TA 1, TA 2, TB 1, and TB 2) and was not detected at the reference site. Carbamazepine was only detected in the surface soil samples. Walker et al. (2012) detected an accumulation of carbamazepine in the surface 30 cm of soil with much lower concentrations detected below. Our results showed that carbamazepine was only extracted through solvent extraction, likely due to its hydrophobicity and log K_{ow} of 2.35. The correlation plots (Figure 7) show strong positive correlations for the concentration of carbamazepine with percent carbon (R^2=0.927) and cation exchange capacity (R^2=0.997). Therefore, soils rich in carbon and with a high cation exchange capacity may be sufficient for reducing the mobility of PPCPs, particularly more hydrophobic compounds like carbamazepine, providing a natural filter to remove micro-pollutants from irrigated wastewater.

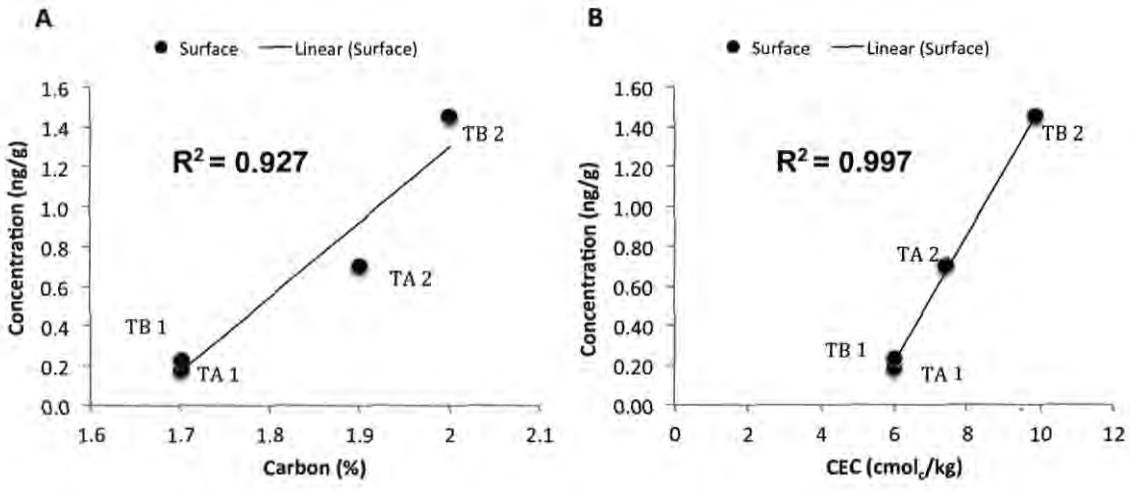

Figure 7: Correlation plots for the concentration of carbamazepine with (A) percent carbon, and (B) cation exchange capacity. No carbamazepine was detected in the deep soil.

In addition to the soil type present, the mobility of PPCPs is also dependent on the amount of the chemical compound applied and the intensity and/or frequency of irrigation and rain events (Drillia et al., 2005). Therefore, the presence of PPCPs and their respective concentrations are also time-dependent. At the municipal land application site in this study, wastewater is irrigated more frequently during times of low precipitation and less frequently during times of high precipitation, in order to keep the hydrological inputs to the forest-system fairly consistent. This alters the inputs of PPCPs into the system and during times of more rainfall could result in greater leaching potential. Additionally, the specific PPCP compounds that are detected at each sampling event can vary greatly due to their presence in the wastewater effluent, which can vary based on changes in human use (Kinney et al., 2006).

Conclusion

Of the 33 PPCPs targeted, 25 were detected in the soil, indicating some adsorption by the soil and mitigation by the forest system. Generally, PPCPs were present at higher concentrations in the surface soil than in the deep soil. However, the presence of these micro-pollutants in both the groundwater and surface water at this site make them of concern to water resources. Although there were no observed correlations between soil characteristics and the presence and concentration of PPCPs, carbamazepine was correlated to soil properties such as cation exchange capacity and carbon, promoting greater adsorption and decreased mobility in the soil profile. In general, the soils at this site have a high sand content allowing for rapid infiltration of irrigated water, potentially not providing the best conditions for PPCP adsorption. There is a growing concern for the presence and persistence of these PPCPs in the environment. The multitude of different chemicals that are classified as PPCPS makes them difficult to study. Further research into the presence, transport, and fate of these chemical contaminants is needed. An increase in the understanding of the environmental and human health effects of these chemicals will indicate if there is greater need for regulation and management of PPCPs in the future.

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Appendix A

Table 4: Range of concentrations of the 25 detected PPCP compounds (ng of PPCP/g of soil).

	TA 1		TA 2		TB 1		TB 2	
Detected Compound	**Surface**	**Depth**	**Surface**	**Depth**	**Surface**	**Depth**	**Surface**	**Depth**
* 17β-estradiol	ND-0.99	0.30-1.2	ND-0.50	ND-0.082	ND-0.35	ND-0.58	ND-0.97	ND-0.46
Atenolol	ND-0.38	ND	ND-0.084	ND	ND	ND	ND	ND
* BPA	ND-3.3	ND-0.62	ND-5.4	ND-3.2	0.020-2.8	ND-4.3	ND	ND-0.35
* Caffeine	ND-0.096	ND-0.14	ND-0.12	0.088-0.12	ND-0.20	ND	ND	ND-0.077
* Carbamazepine	0.12-0.24	ND	0.53-1.0	ND	0.22-0.23	ND	1.3-1.6	ND
* Cotinine	ND-0.11	ND-0.074	ND	ND-0.11	ND	ND	ND	ND
* DEET	1.4-21	2.5-10	1.3-80	1.0-5.3	2.9-3.2	2.1-5.9	2.2-9.9	2.1-5.2
* Diltiazem	ND-0.50	ND	ND	ND	ND	ND-0.075	ND	ND
* Diphenhydramine	0.12-0.36	ND	ND-0.076	ND	ND	ND-0.21	ND	ND

Detected Compound	TA 1		TA 2		TB 1		TB 2	
	Surface	Depth	Surface	Depth	Surface	Depth	Surface	Depth
* Estriol	ND	ND	ND	ND	ND	ND-0.97	ND	ND-0.087
* Estrone	ND	ND	ND	ND	ND	ND	ND-0.06	ND-0.04
* Fluoxetine	ND-1.2	ND-0.31	ND-0.13	ND-0.51	0.10-0.19	0.14-0.50	0.85-1.8	0.50-1.0
* Gemfibrozil	0.16-0.27	ND-0.60	ND-0.59	0.11-1.2	ND-0.21	0.12-0.59	0.075-0.38	ND-0.24
* Ibuprofen	ND	ND	ND	ND	ND	ND-2.9	ND	ND
Meprobamate	ND-0.41	ND-0.48	ND	ND-0.87	0.35-0.79	0.28-0.52	ND-0.62	0.84-1.1
* Naproxen	ND	ND-0.13	ND-0.61	ND	ND-0.33	ND	0.38-0.48	ND-0.30
* Paraxanthine	ND-0.16	ND	ND	ND	ND	ND	ND	ND
* Paroxetine	0.13-1.5	ND-0.086	ND	ND	ND	ND-0.080	ND	ND
* Progesterone	ND-0.11	ND	ND-0.32	ND-0.076	ND-0.095	ND	0.097-0.41	ND-0.30
* Salicylic Acid	ND-1.4	ND-0.86	ND-1.4	ND-0.66	ND	ND	ND	ND

Detected Compound	TA 1		TA 2		TB 1		TB 2	
	Surface	Depth	Surface	Depth	Surface	Depth	Surface	Depth
* Triamterene	ND-0.15	ND-0.14	ND-0.12	ND-0.080	ND-0.11	ND	0.28-0.49	ND
Triclocarban	ND	ND-0.080	ND	ND	ND	ND	ND	ND
* Triclosan	ND-0.37	ND-0.45	ND-0.49	ND-0.41	ND	ND	ND-0.10	ND-0.18
* Trimethoprim	ND-1.2	ND-0.073	ND	ND-0.11	ND	ND	ND	ND
* Valsartan	ND-0.074	ND	ND	ND	ND	ND	ND	ND

* PPCP present in groundwater at site.

Table 5: PPCP concentrations (ng of PPCP/g of soil) from the June 10, 2015 sampling event.

PPCP Compound	TA 1		TA 2	
	0-10 cm	60 cm	0-10 cm	60 cm
17β-estradiol	ND	0.30	ND	ND
Acetaminophen	ND	ND	ND	ND
Atenolol	ND	ND	ND	ND
Azithromycin	ND	ND	ND	ND
BPA	3.3	0.11	5.4	ND
Caffeine	0.096	0.082	0.12	0.088
Carb C13	3.2	3.9	3.4	3.9
Carbamazepine	0.24	ND	0.53	ND
Cholesterol	ND	ND	ND	ND
Cotinine	ND	0.074	ND	0.11
DEET	21	11	80	1.3
Diltiazem	ND	ND	ND	ND
Diphenhydramine	0.12	ND	ND	ND
Estrone	ND	ND	ND	ND
E2 C13	ND	0.46	ND	0.45

PPCP Compound	TA 1		TA 2	
	0-10 cm	60 cm	0-10 cm	60 cm
EE2	1.6	ND	2.9	0.71
Erythromycin	ND	ND	ND	ND
Estriol	ND	ND	ND	ND
Estrone	ND	ND	ND	ND
Fluoxetine	ND	ND	ND	ND
Gemfibrozil	0.25	0.60	0.59	1.2
Ibuprofen	ND	ND	ND	ND
Lincomycin	ND	ND	ND	ND
Meprobamate	ND	ND	ND	ND
Naproxen	ND	ND	0.21	ND
Paraxanthine	ND	ND	ND	ND
Paroxetine	0.45	ND	ND	ND
Progesterone	ND	ND	ND	0.076
Salicylic Acid	1.4	0.86	1.4	0.66
Sulfamethazine	ND	ND	ND	ND
Sulfamethoxazole	ND	ND	ND	ND

PPCP Compound	TA 1		TA 2	
	0-10 cm	60 cm	0-10 cm	60 cm
Testosterone	ND	ND	ND	ND
Triamterene	ND	ND	ND	ND
Triclocarban	ND	0.080	ND	ND
Triclosan	0.37	0.45	0.49	0.41
Trimethoprim	ND	0.073	ND	0.11
Tylosin	ND	ND	ND	ND
Valsartan	0.074	ND	ND	ND

Table 6: PPCP concentrations (ng of PPCP/g of soil) from the June 30, 2015 sampling event.

PPCP Compound	TA 1		TA 2		TB 1		TB 2	
	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm
17β-estradiol	0.32	0.70	0.50	0.082	0.35	ND	0.97	0.46
Acetaminophen	ND	ND	ND	ND	ND	ND	ND	ND
Atenolol	0.23	ND	ND	ND	ND	ND	ND	ND
Azithromycin	ND	ND	ND	ND	ND	ND	ND	ND
BPA	ND	ND	ND	ND	2.8	ND	ND	ND

	TA 1		TA 2		TB 1		TB 2	
PPCP Compound	**0-10 cm**	**60 cm**	**0-10 cm**	**60 cm**	**0-10 cm**	**60 cm**	**0-10 cm**	**60 cm**
Caffeine	ND	ND	ND	ND	ND	ND	ND	ND
Carb C13	34	49	30	51	44	84	58	43
Carbamazepine	0.18	ND	0.53	ND	0.22	ND	1.3	ND
Cholesterol	ND	ND	ND	ND	ND	ND	ND	ND
Cotinine	0.11	ND	ND	ND	ND	ND	ND	ND
DEET	1.4	2.5	1.3	1.0	2.9	2.1	2.1	2.1
Diltiazem	0.50	ND	ND	ND	ND	0.075	ND	ND
Diphenhydramine	0.21	ND	ND	ND	ND	0.21	ND	ND
Estrone	ND	ND	ND	ND	ND	ND	0.12	0.080
E2 C13	ND	ND	0.40	0.24	ND	0.22	ND	0.19
EE2	ND	1.1	ND	ND	8.9	ND	ND	6.7
Erythromycin	ND	ND	ND	ND	ND	ND	ND	ND
Estriol	ND	ND	ND	ND	ND	0.97	ND	0.087
Estrone	ND	ND	ND	ND	ND	ND	ND	ND
Fluoxetine	0.61	0.25	ND	0.51	0.19	0.14	1.8	1.0
Gemfibrozil	0.16	ND	ND	0.11	ND	0.12	0.075	ND

PPCP Compound	TA 1		TA 2		TB 1		TB 2	
	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm	0-10 cm	60 cm
Ibuprofen	ND	ND	ND	ND	ND	ND	ND	ND
Lincomycin	ND	ND	ND	ND	ND	ND	ND	ND
Meprobamate	0.16	0.48	ND	0.87	0.35	0.28	ND	1.1
Naproxen	ND	0.13	ND	ND	ND	ND	0.48	0.30
Paraxanthine	0.16	ND	ND	ND	ND	ND	ND	ND
Paroxetine	1.5	ND	ND	ND	ND	0.080	ND	ND
Progesterone	0.094	ND	ND	ND	ND	ND	0.41	0.30
Salicylic Acid	ND	ND	ND	ND	ND	ND	ND	ND
Sulfamethazine	ND	ND	ND	ND	ND	ND	ND	ND
Sulfamethoxazole	ND	ND	ND	ND	ND	ND	ND	ND
Testosterone	ND	ND	ND	ND	ND	ND	ND	ND
Triamterene	0.15	ND	ND	ND	0.11	ND	0.49	ND
Triclocarban	ND	ND	ND	ND	ND	ND	ND	ND
Triclosan	ND	ND	ND	ND	ND	ND	0.099	0.18
Trimethoprim	1.2	ND	ND	ND	ND	ND	ND	ND
Tylosin	ND	ND	ND	ND	ND	ND	ND	ND

	TA 1		TA 2		TB 1		TB 2	
PPCP Compound	**0-10 cm**	**60 cm**	**0-10 cm**	**60 cm**	**0-10 cm**	**60 cm**	**0-10 cm**	**60 cm**
Valsartan	ND	ND	ND	ND	ND	ND	ND	ND

Table 7: PPCP concentrations (ng of PPCP/g of soil) from the July 15, 2015 sampling event.

	TA 1		TA 2		TB 1		TB 2	
PPCP Compound	**0-10 cm**	**60 cm**	**0-10 cm**	**60 cm**	**0-10 cm**	**60 cm**	**0-10 cm**	**60 cm**
17β-estradiol	0.99	1.2	0.28	ND	ND	0.58	ND	ND
Acetaminophen	ND	ND	ND	ND	ND	ND	ND	ND
Atenolol	0.38	ND	0.084	ND	ND	ND	ND	ND
Azithromycin	ND	ND	ND	ND	ND	ND	ND	ND
BPA	0.014	0.62	0.027	3.2	0.020	4.3	ND	0.35
Caffeine	ND	0.14	ND	0.12	0.20	ND	ND	0.077
Carb C13	33	45	36	62	34	54	45	47
Carbamazepine	0.12	0	1.0	ND	0.23	ND	1.6	ND
Cholesterol	ND	ND	ND	ND	ND	ND	ND	ND
Cotinine	ND	ND	ND	ND	ND	ND	ND	ND
DEET	5.5	3.7	5.1	5.3	3.2	5.9	9.9	5.2

Diltiazem	ND	ND	ND	ND	ND	ND	ND	ND
Diphenhydramine	0.36	ND	0.076	ND	ND	ND	ND	ND
Estrone	ND	ND	ND	ND	ND	ND	ND	ND
E2 C13	ND	ND	ND	ND	ND	ND	ND	ND
EE2	2.5	ND	0.44	0.39	ND	ND	0.10	0.16
Erythromycin	ND	ND	ND	ND	ND	ND	ND	ND
Estriol	ND	ND	ND	ND	ND	ND	ND	ND
Estrone	ND	ND	ND	ND	ND	ND	ND	ND
Fluoxetine	1.2	0.31	0.13	ND	0.10	0.50	0.85	0.50
Gemfibrozil	0.27	0.20	0.30	0.26	0.21	0.59	0.38	0.24
Ibuprofen	ND	ND	ND	ND	ND	2.9	ND	ND
Lincomycin	ND	ND	ND	ND	ND	ND	ND	ND
Meprobamate	0.41	0.12	ND	ND	0.79	0.52	0.62	0.84
Naproxen	ND	ND	0.61	ND	0.33	ND	0.38	ND
Paraxanthine	ND	ND	ND	ND	ND	ND	ND	ND
Paroxetine	0.13	0.086	ND	ND	ND	ND	ND	ND
Progesterone	0.11	ND	0.32	ND	0.095	ND	0.097	ND
Salicylic Acid	ND	ND	ND	ND	ND	ND	ND	ND

Sulfamethazine	ND	ND	ND	ND	ND	ND	ND	ND
Sulfamethoxazole	ND	ND	ND	ND	ND	ND	ND	ND
Testosterone	ND	ND	ND	ND	ND	ND	ND	ND
Triamterene	0.082	0.14	0.12	0.080	ND	ND	0.28	ND
Triclocarban	ND	ND	ND	ND	ND	ND	ND	ND
Triclosan	0.14	ND	0.20	ND	ND	ND	ND	ND
Trimethoprim	ND	ND	ND	ND	ND	ND	ND	ND
Tylosin	ND	ND	ND	ND	ND	ND	ND	ND
Valsartan	ND	ND	ND	ND	ND	ND	ND	ND

Appendix B

NORFOLK SERIES

LOCATION NORFOLK NC+AL AR FL GA SC VA
Established Series
CMO/Rev. JAK
11/2005

MLRA(s): 133A-Southern Coastal Plain, 153A-Atlantic Coast Flatwoods, 153B-Tidewater Area
MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: Raleigh, North Carolina
Depth Class: Very deep
Drainage Class (Agricultural): Well drained
Internal Free Water Occurrence: Deep, transitory or very deep
Index Surface Runoff: Negligible to medium
Permeability: Moderate (Saturated Hydraulic Conductivity: Moderately high)
Landscape: Lower, middle, or upper coastal plain
Landform: Uplands or marine terraces
Geomorphic Component: Interfluve, side slopes
Hillslope Profile Position: Summits, shoulders, backslopes
Parent Material: Marine deposits or fluviomarine deposits
Slope: 0 to 10 percent
Elevation (type location): Unknown
Mean Annual Air Temperature (type location): 62 degrees F.
Mean Annual Precipitation (type location): 49 inches

TAXONOMIC CLASS: Fine-loamy, kaolinitic, thermic Typic Kandiudults

TYPICAL PEDON: Norfolk loamy sand--cultivated. (Colors are for moist soil unless otherwise indicated.)

Ap--0 to 9 inches; grayish brown (10YR 5/2) loamy sand; weak fine and medium granular structure; very friable; nonsticky, nonplastic; few fine and medium roots; darker-colored material in old root channels; strongly acid; clear smooth boundary. (3 to 10 inches thick)

E--9 to 14 inches; light yellowish brown (10YR 6/4) loamy sand; weak medium granular structure; very friable; nonsticky, nonplastic; few fine and medium roots; darker-colored material in old root channels; strongly acid; clear smooth boundary. (0 to 10 inches thick)

Bt1--14 to 17 inches; yellowish brown (10YR 5/6) sandy loam; weak medium subangular blocky structure; friable; slightly sticky, slightly plastic; few fine and medium roots; few faint clay films on faces of peds; strongly acid; clear wavy boundary.

Bt2--17 to 38 inches; yellowish brown (10YR 5/6) sandy clay loam; weak medium subangular blocky structure; friable; slightly sticky, slightly plastic; many fine and medium pores; few faint clay films on faces of peds; strongly acid; gradual wavy boundary.

Bt3--38 to 58 inches; yellowish brown (10YR 5/6) sandy clay loam; weak medium subangular blocky structure; friable; slightly sticky, slightly plastic; few faint clay films on faces of peds; few fine faint strong brown (7.5YR 4/6) and few prominent yellowish red (5YR 5/8) masses of oxidized iron and few fine distinct pale brown (10YR 6/3) iron depletions; strongly acid; gradual wavy boundary.

Bt4--58 to 70 inches; yellowish brown (10YR 5/6) sandy clay loam; weak medium subangular blocky structure; friable; slightly sticky, slightly plastic; few faint clay films on faces of peds; common medium distinct yellowish red (5YR 5/8) masses of oxidized iron and pale brown (10YR 6/3) and light brownish gray (10YR 6/2) iron depletions; 1 percent, firm yellowish red plinthite nodules; strongly acid; gradual wavy boundary. (Combined thickness of Bt horizon is 40 to more than 60 inches.)

BC--70 to 82 inches; variegated brownish yellow (10YR 6/6), strong brown (7.5YR 5/6), and yellowish red (5YR 5/6) sandy clay loam; weak medium subangular blocky structure; friable; slightly sticky, slightly plastic; 5 percent firm, brittle plinthite nodules; strongly acid; gradual wavy boundary. (0 to more than 15 inches thick)

C--82 to 100 inches; variegated red (2.5YR 4/8), strong brown (7.5YR 5/8), brownish yellow (10YR 6/8) and gray (10YR 5/1) sandy clay loam; massive; friable; slightly sticky, slightly plastic; strongly acid.

TYPE LOCATION: Robeson County, North Carolina; 1.25 miles south of Parkton; 300 feet west of State Road 1724 and 60 feet south of farm road.

RANGE IN CHARACTERISTICS:
Thickness of the sandy surface and subsurface layers: 3 to 19 inches
Depth to top of the Argillic horizon: 3 to 19 inches
Depth to the base of the Argillic horizon: 60 to more than 80 inches
Depth to top of the Kandic horizon: 3 to 19 inches
Depth to bedrock: Greater than 80 inches
Depth to Seasonal High Water Table: 40 to 72 inches, January to March
Soil Reaction: Extremely acid to strongly acid, throughout except where limed
Rock Fragment Content: 0 to 5 percent, by volume throughout; mostly quartz pebbles or ironstone nodules
Plinthite Content: 0 to 4 percent to a depth of 60 inches and 0 to 10 percent or more below 60 inches

RANGE OF INDIVIDUAL HORIZONS:
Ap horizon or A horizon (where present):
Color--hue of 10YR or 2.5Y, value of 4 to 7, chroma of 1 to 4
Texture--loamy sand, sandy loam, fine sandy loam, or loamy fine sand. Some pedons are fine sand or sand.

E horizon:
Color--hue of 10YR or 2.5Y, value of 4 to 7, chroma of 2 to 6
Texture--loamy sand, sandy loam, fine sandy loam, or loamy fine sand. Some pedons are fine sand or sand.

BE horizon (where present):
Color--hue of 10YR or 2.5Y, value of 4 to 6, chroma of 3 to 8
Texture--sandy loam or fine sandy loam

Bt horizon (upper):
Color--hue of 7.5YR to 2.5Y, value of 5 to 8, chroma of 3 to 8
Texture--sandy loam, fine sandy loam, sandy clay loam, or clay loam

Redoximorphic features (where present)--masses of oxidized iron in shades of red, yellow, or brown and iron depletions in shades of brown, yellow, or olive

Bt horizon (lower):
Color--hue of 7.5YR to 2.5Y, value of 5 to 8, chroma of 3 to 8
Texture--sandy loam, fine sandy loam, sandy clay loam, clay loam, sandy clay, or clay
Redoximorphic features--masses of oxidized iron in shades of red, yellow, or brown and iron depletions in shades of brown, yellow, olive, or gray

BC horizon or BCt horizon (where present):
Color--hue of 5YR to 2.5Y, value of 4 to 7, chroma of 3 to 8, or variegated in shades of these colors
Texture--sandy loam, fine sandy loam, sandy clay loam, clay loam, sandy clay, or clay
Redoximorphic features--masses of oxidized iron in shades of red, yellow, or brown and iron depletions in shades of brown, yellow, olive, or gray

C horizon:
Color--hue of 2.5YR to 5Y, value of 4 to 8, chroma of 3 to 8, or is variegated in shades of these colors
Texture--loamy coarse sand, loamy sand, loamy fine sand, coarse sandy loam, sandy loam, fine sandy loam, sandy clay loam, clay loam, or sandy clay. Some pedons have layers of coarser or finer textured materials.
Redoximorphic features--masses of oxidized in shades of red, yellow, or brown and iron depletions in shades of brown, yellow, olive, or gray

COMPETING SERIES:
Orangeburg soils--have hue of 5YR or redder throughout the Bt horizon
Thursa soils--have hue of 5YR or redder below the upper 10 inches of the Bt horizon

GEOGRAPHIC SETTING:
Landscape: Lower, middle, or upper coastal plain
Landform: Uplands or marine terraces
Geomorphic Component: Interfluve, side slopes
Hillslope Profile Position: Summits, shoulders, backslopes
Parent Material: Marine deposits or fluviomarine deposits
Elevation: 30 to 450 feet
Mean Annual Air Temperature: 57 to 70 degrees F.
Mean Annual Precipitation: 35 to 55 inches
Frost Free Period: 190 to 245 days

GEOGRAPHICALLY ASSOCIATED SOILS:
Aycock soils--are in a fine-silty family
Bonneau soils--have an arenic soil surface
Butters soils--are in a coarse-loamy family
Caroline soils--are in a fine family
Craven soils--are in a fine family
Duplin soils--are in a fine family
Exum soils--are in a fine-silty family
Faceville soils--are in a fine family
Foreston soils--are in a coarse-loamy family
Goldsboro soils--are moderately well drained
Marlboro soils--are in a fine family
Noboco soils--have siliceous mineralogy
Lakeland soils--are sandy throughout
Lynchburg soils--are somewhat poorly drained
Rains soils--are poorly drained soils
Orangeburg soils--have hue of 5YR or redder throughout the Bt horizon

Pantego soils--are very poorly drained soils
Thursa soils--have hue of 5YR or redder below the upper 10 inches of the Bt horizon
Wagram soils--have an arenic soil surface

DRAINAGE AND PERMEABILITY:
Depth Class: Very deep
Drainage Class (Agricultural): Well drained
Internal Free Water Occurrence: Deep, transitory or very deep
Index Surface Runoff: Negligible to medium
Permeability: Moderate (Saturated Hydraulic Conductivity: Moderately high)

USE AND VEGETATION:
Major Uses: Mostly cleared and used for general farm crops.
Dominant Vegetation: Where cultivated--corn, cotton, peanuts, tobacco, and soybeans. Where wooded--pines and mixed hardwoods.

DISTRIBUTION AND EXTENT:
Distribution: Alabama, Arkansas, Florida, Georgia, North Carolina, South Carolina, and Virginia
Extent: Large

MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: Raleigh, North Carolina

SERIES ESTABLISHED: Cecil County, Maryland; 1900.

REMARKS: The June, 1988 revision recognized the low activity clay properties of this soil as defined in the low activity clay amendment of Soil Taxonomy, August
1986. 10/2004, changed water table from 4.0-6.0 ft to 3.3-6.0 ft to cover depth that would be included in the typic subgroup versus associated soils in the Oxyaquic subgroup. Diagnostic horizons and features recognized in this pedon are:
Ochric epipedon--the zone from the surface to a depth of 14 inches (A and E horizons)
Kandic horizon--the zone between 14 and 70 inches (Bt horizon)
Argillic horizon--the zone between depths of 14 and 70 inches (Bt horizon)

ADDITIONAL DATA: (1) U.S. Department of Agriculture, Soil Survey Laboratory Data and Descriptions for Some Soils of Georgia, North and South Carolina. Soil Survey Investigations Report No. 16; SCS, in cooperation with Georgia, North Carolina, and South Carolina Agricultural Experiment Stations; Pages 65, 67, 69. (2) U.S. Department of Agriculture, Certain Properties of Selected Southeastern United States Soils and Mineralogical Procedures for Their Study, Southern Cooperative Series Bulletin 61 (S-14); Soil Conservation Service, Agricultural Research Service and cooperating Experiment Stations; tables 64, 67, 68. (3) U.S. Department of Agriculture, Selected Coastal Plain Soil Properties, Southern Cooperative Service and cooperating Experiment Stations; pages 40, 42, 44, 46.

National Cooperative Soil Survey
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